Using preexisting cleavage to define extensional fault geometries: An example from Glacier National Park, Montana

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ABSTRACT

The geometry of the Rocky Mountain trench extensional fault system in northwest Montana can be defined by using, as reference features, pervasive asymmetric cleavages associated with the preexisting Lewis thrust. These Laramide fabrics act as preextensional markers of regional dip and elevation, and thus deformation of these passive markers can be used to determine the specific hanging-wall geometry of each extensional fault.

Two types of extensional fault are distinguished: (1) planar faults with tilt-block geometries that cut through the Lewis thrust, and (2) curved faults with rollover geometries that reactivate the existing Lewis thrust. The deformed Laramide markers indicate that the Rocky Mountain trench system is dominated by a series of tilt blocks upon which the preexisting thrust had only a localized effect.

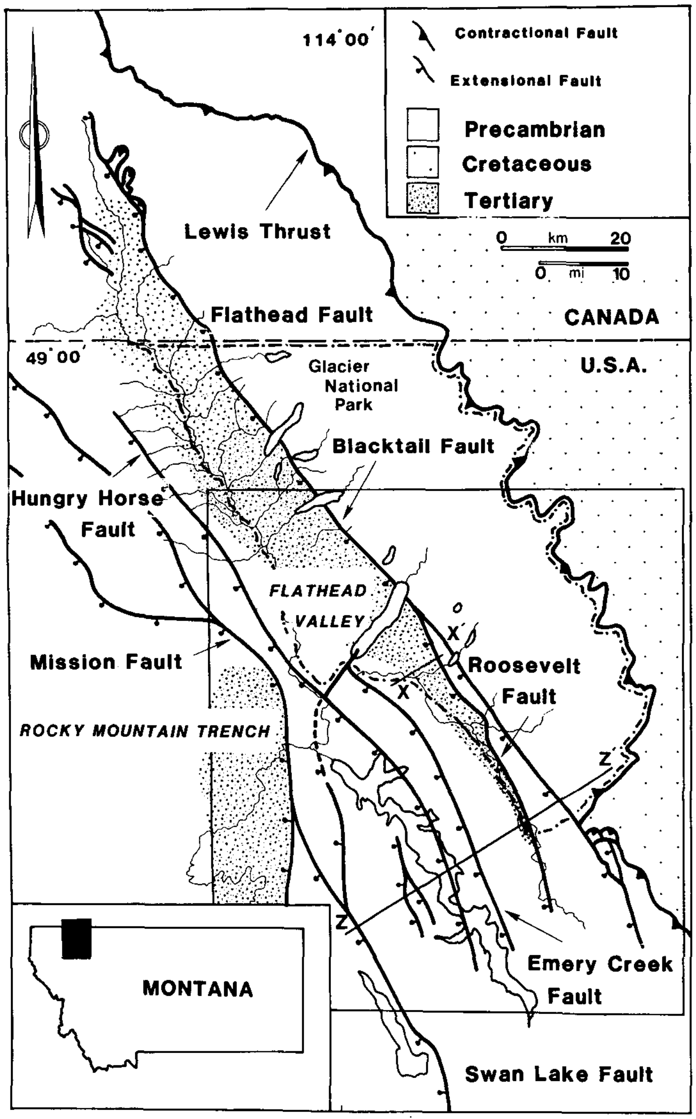

Figure 1. Generalized geology of Glacier National Park area showing position of major contractional and extensional lineaments. (Inset shows location of Fig. 5.) Regional data partly from Childers (1963), Earhart et al. (1983), and Ross (1959).

INTRODUCTION

Glacier National Park lies within the Front Ranges of the Rocky Mountains in northwestern Montana (Fig. 1). Previous workers (Ross, 1959; Childers, 1963; Constenius, 1982; Mudge and Earhart, 1983) have highlighted the presence of large-scale contractional and extensional structures within the area and have suggested possible interactions between the two.

The major contractional feature of the area is the Laramide Lewis thrust (Fig. 1). This thrust trends northwest-southeast, separating the Rocky Mountain Front Ranges to the southwest from the foothills to the northeast, and dips shallowly southwest at 15° (Ross, 1959). Parallel to the thrust trend, the Precambrian Belt Supergroup of the thrust hanging wall is cut by several extensional faults of Oligocene age (Fig. 1). The most westerly feature of this extensional fault system is the Rocky Mountain trench which extends from Montana north into British Columbia. This Tertiary fault system, the Rocky Mountain trench extensional system (Powell and Williams, 1988), overprints contractional structures associated with the earlier thrusting of Cretaceous age.

DETERMINATION OF EXTENSIONAL GEOMETRIES USING CONTRACTIONAL STRUCTURES

Small-scale contractional structures associated with the Lewis thrust include minor-scale thrusts and associated asymmetric folds (F_1) containing an axial planar cleavage (S_1). The S_1 cleavage is pervasive, attaining a marked asymmetry in incompetent beds indicative of an overriding north-

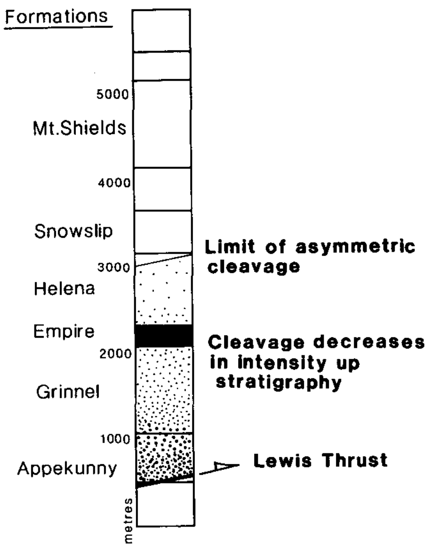

Figure 2. Position of asymmetric "cleavage zone" within Precambrian stratigraphy of Glacier National Park area.

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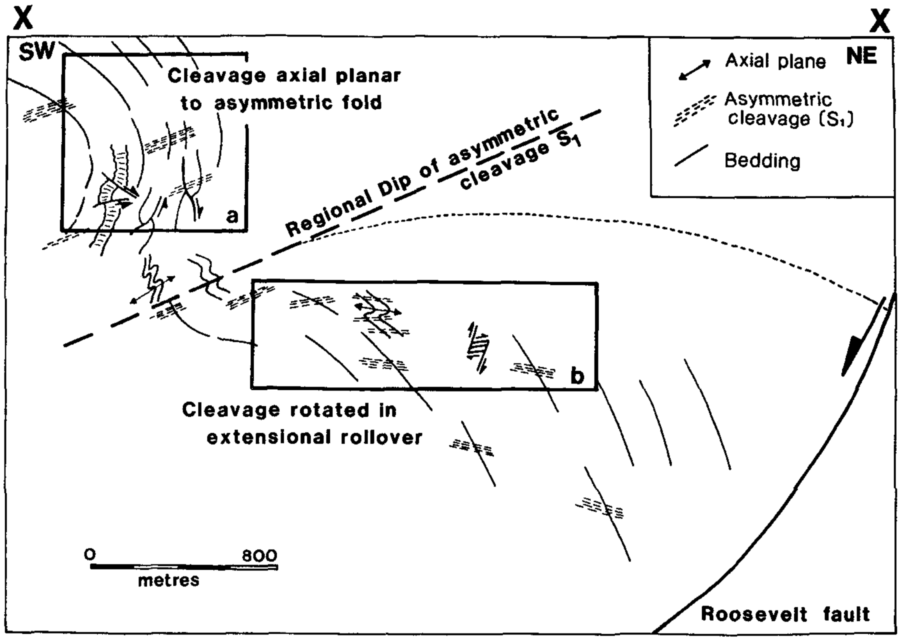
Figure 3. Use of Laramide cleavage rotation to determine extensional hanging-wall geometry of Roosevelt fault. Position of cross section X-X′ through Roosevelt fault is shown in Figure 1.



easterly directed shear related to the emplacement of the Lewis thrust sheet. The cleavage is an important marker because it occurs in a zone of specific thickness directly above the Lewis thrust (Fig. 2). The thickness of this cleavage zone is consistent (1950 m thick) throughout the Glacier National Park area (complete sections are measureable both on the east side of the park and on the east side of Hungry Horse reservoir), and thus the horizon at which the cleavage dies out above the thrust is a mappable surface from which the present depth to the Lewis thrust can be calculated and contoured.

In order to determine the geometry of any individual extensional fault in the system, the attitude of the asymmetric contractional cleavage can be used. The regional dip of the cleavage is a constant contractional marker within the thrust sheet. In the Glacier Park region, the cleavage dips at 27°SW when bedding is horizontal, and the deviation of the cleavage from this dip may be used to predict any later hanging-wall extensional geometry.

The bedding in the hanging wall ~1.5 km southwest of the Roosevelt fault appears to be deformed into an extensional rollover geometry (a in Fig. 3), with steep dips toward the fault. Although the bedding is increasing in dip toward the extensional fault, the pervasive S_1 cleavage maintains a constant dip. The cleavage is axial planar to a Laramide-age contractional asymmetrical fold, and the dip of the bedding is deviating from its regional dip due to a contractional structure rather than an extensional rollover.

One kilometre to the east, closer to the Roosevelt fault trace, the flat limb of the contractional fold becomes tilted toward the fault. The cleavage here maintains a consistent angle to bedding, becoming downward facing, i.e., eastward dipping, as the bedding is rotated (b in Fig. 3). It is the cleavage rather than the bedding that defines the true extensional rollover anticline of the Roosevelt fault.

In a similar fashion, if the preextensional cleavage dip is known, rotation of the cleavage in the footwall of an extensional fault can be determined. This could define whether a flexure is truly extensional in nature or if it is augmented by an earlier contractional fold. The fundamental principle is that where F_1 fold hinges are absent the cleavage/bedding angle is consistent and maintained throughout later extensional deformation. In listric fault geometries, the cleavage fans from a westerly regional dip to become easterly dipping in the immediate hanging wall to the fault, whereas in tilt blocks the cleavage has a consistent angle to the horizontal in the hanging wall of each fault.

On a regional scale, the distribution of asymmetric cleavage throughout the Glacier National Park region can be used to calculate the geometry of the extensional fault system as a whole, allowing the existing model for the extensional system to be tested. In this existing model (Mudge and Earhart, 1983; Earhart et al., 1983), the extensional faults have listric geometries, detaching into the Lewis thrust and reactivating it as an extensional feature (Fig. 4a, 4b). A preexisting fold in the Lewis thrust surface generated by a thrust ramp (Constenius, 1982) causes a corresponding fold in the bedding and a position of nucleation for the most easterly fault. This geometry for the Lewis thrust would require the cleavage zone to be folded, which would affect the cleavage distribution (Fig. 4a). The upward limit of the cleavage zone would remain below the height projected across from the undeformed footwall to the extensional system, i.e., the regional elevation of the cleavage zone (Powell and Williams, 1988). No cleavage would be present at the surface throughout the Glacier National Park area (Fig. 4b). This is demonstrably not the case. To corroborate this evidence against listric fault profiles, the regional dip of the bedding within the Belt Supergroup does not steepen appreciably into a fold in the vicinity of the Blacktail fault, but rather into an extensional flexure; the cleavage steepens with the bedding. This appears to suggest independently that no sizable thrust ramp exists in this area.

An alternative model is presented in Figure 4c and 4d; the extensional faults are dominantly deep, throughgoing, essentially planar structures that displace the Lewis thrust together with the Precambrian stratigraphy in the thrust sheet. Such faults do not reactivate the preexisting thrust but cut through it (Powell and Williams, 1988). In this model no ramp in the Lewis thrust is necessary to generate listric faults, and therefore the cleavage zone would not drop below its regional elevation in the hanging wall of the extensional system (Fig. 4c). Planar throughgoing faults would displace not only the thrust but also the cleavage zone in a series of tilt blocks. The cleavage would be found on the footwall side of each extensional fault, the upward limit of the cleavage being a mappable horizon within each fault block (Fig. 4d). This model fits the distribution of asymmetric cleavage in the Glacier National Park area (Fig. 5).

DISCUSSION

The dominance of tilt-block geometries within the Rocky Mountain trench fault system can be seen on a cross section from the Rocky Mountain trench to the Lewis thrust front. The cross section illustrates the position of the "cleavage zone" and the Lewis thrust and their relation to the extensional fault system (Fig. 6). The Roosevelt and Hungry Horse faults are the exceptions to the tilt-block model in that they have listric

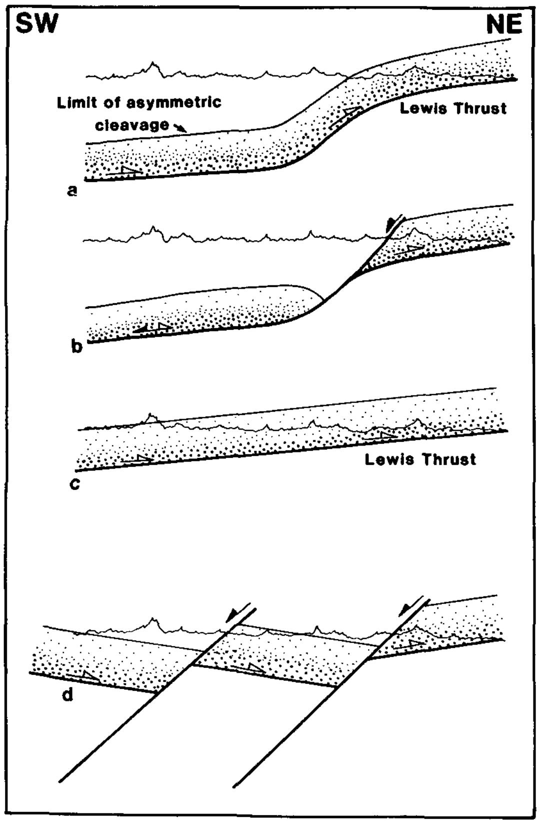


Figure 4. Models for extensional fault geometries with respect to preexisting cleavage. a: Preextensional fold in Lewis thrust sheet with reactivation of steep part of Lewis thrust by listric, shallowly detaching extensional faults. b: Deep throughgoing extensional faults with no reactivation of Lewis thrust. Open arrow indicates thrust movement; solid arrow indicates extensional movement. Intensity of stipple equates to intensity of Laramide asymmetric cleavage.

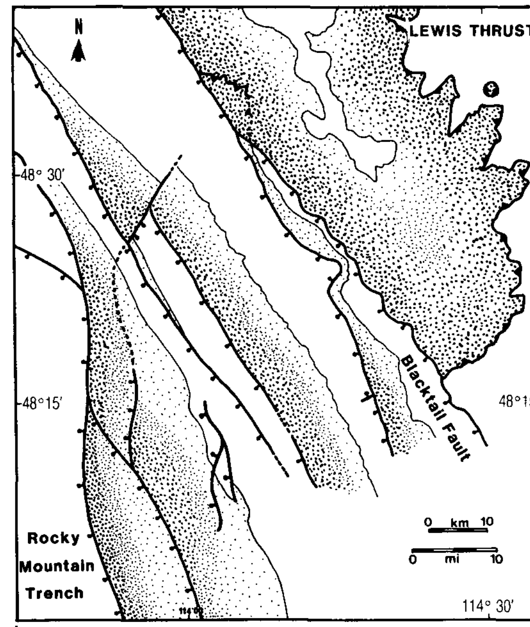


Figure 5. Distribution of asymmetric cleavage within Glacier National Park area. Intensity of stipple equates to S_1 cleavage intensity.

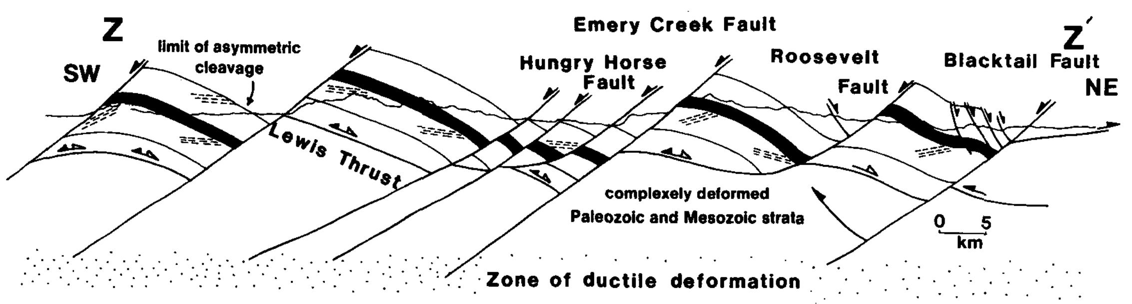


Figure 6. Cross section (Z-Z′) from Rocky Mountain trench to Lewis thrust showing limit of asymmetric cleavage and geometry of extensional fault system. Open arrows indicate thrust movement; solid arrows indicate extensional movement. Stratigraphic patterns as in Figure 2.

fault geometries and corresponding hanging-wall rollovers defined by rotation of cleavage through the horizontal. These two faults detach into the Lewis thrust and reactivate this preexisting thrust, in contrast to the Blacktail and Emery Creek faults, which have planar geometries and displace the Lewis thrust. The cleavage has a consistent dip throughout the hanging walls of these faults. The planar faults must propagate to a depth of at least 15 km by virtue of their hanging-wall geometries.

In Glacier National Park, the presence of the preexisting Lewis thrust system has had a localized and specific influence on those structures produced during a later deformational episode, the Rocky Mountain trench extensional system. The degree of influence on any individual extensional fault can be determined using the deformation of preexisting contractional markers, in this case a pervasive asymmetric cleavage. The use of such small-scale structures is helpful, because bedding geometries alone may provide considerable ambiguity in a multideformational region.

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